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THE FISH RESCUE PROJECT AT THE PACIFIC GAS AND ELECTRIC COMPANY'S CONTRA COSTA STEAM PLANT

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James E. Kerr

Introduction

Making the most of our natural resources at times poses a complex problem. Particularly is this true in the utilization of two or more natural resources when by the use of one an apparent conflict exists in the use of the other.

Such a problem is the industrial use of water from the waterways of the United States and at the same time the preservation of fish inhabitants.

With the expanding requirements for water in greater and greater quantities and the increasing consciousness of Federal, State and sportsmen's groups in the conservation of fish and wildlife, the problem is being rapidly forced to the forefront.

Federal and State regulations control the use, diversion and pollution of public waters and from time to time new regulations are added. Electric utility companies in Oregon and Washington now are finding restrictions placed on building new hydroelectric plants due to endangering fishlife. Country-wide, the problem is being felt where the conservation of fishlife is involved and not always is the problem faced realistically.

In some quarters it is argued the two interests, fishlife and the industrial use of water, are not compatible and that one will have to be sacrificed to the other.

The Contra Costa Steam Plant of the Pacific Gas and Electric Company, engineered and constructed by the Bechtel Corporation, was confronted with the problem of preserving fishlife and at the same time using large quantities of water from the San Joaquin River. The two principal fisheries involved were striped bass and king salmon.

The Plant Location - Delta Area

The plant is built on the south bank of the San Joaquin River approximately two and one-half miles upstream from the city of Antioch, California.

The area is referred to as the Delta. It is here that the Sacramento and the San Joaquin Rivers flow into Suisun Bay, an arm of San Francisco Bay. The two great rivers are interlaced by many cross channels, forming a delta area of sloughs, low islands, and tule marshes. Tidal conditions prevail and during the summer months salinity runs as high as 2000 to 3000 parts per million. Extreme tidal range is approximately 8 feet at the plant site.

Fisheries of the Area

The Delta abounds in fish life. Both anadromous and resident fish of many species are to be found here.

Anadromous fish are defined as those fish which ascend rivers from the sea at certain seasons for breeding, and in this category we have the king salmon, the striped bass, shad, steelhead trout, pacific lamprey eel, two species of smelt, white and green sturgeon, and others. The Delta is the nursery ground for striped bass.

Of the fishery resources of the state, striped bass and king salmon are by far the most important.

The striped bass fishery has been protected against commercial fishing since 1931 and is caught only as a sports fish. As an industry it is estimated that 200,000 anglers catch about 1,500,000 bass a year, and that $10,000,000 is spent annually on bass fishing.(1)

The king salmon fishery is an important resource of the State of California. Attributable to this area, the estimated annual commercial catch of king salmon is 5,600,000 pounds, and added to this is 63,000 pounds caught by sports fishermen.(2)

Resident fish of the Delta include catfish, largemouthed bass, black crappie, bluegill, warmmouthed bass, carp, splittail, squawfish, suckers, hardhead hitch, perch, sculpin, and others. Fish in this category have little commercial or sports value and no special consideration was given them in this project. It is believed, however, that the measures taken for the preservation of striped bass and king salmon will be effective in saving resident fishlife.

The Contra Costa Steam Plant

The first three units of the plant consist of steam turbo-generators with a rated capacity of 100,000 kilowatts each. Construction work was begun in February of 1949, and the three units were placed in operation during the early summer of 1951. Construction work for two additional units, each of the same rated capacity as the first three, was begun in the fall of 1950. These added units are scheduled for operation during the early spring of 1953.

The Condenser Cooling Water System

The initial river water requirements for the first three units is 623 cu. ft./sec., and the ultimate water requirements for the five-unit plant operation will be 868 cu. ft./sec. Water is withdrawn from the river near the bottom at a headwork 410 feet offshore. From the headwork the water is carried to an onshore screen structure through two 12-foot diameter reinforced concrete tubes. Water velocity in the tubes initially is 2.7 ft./sec., and for ultimate full load operation the velocity will be 3.8 ft./sec. The water is screened in the screen structure by five standard type traveling screens. Each screen is basketed with $\frac{3}{8}$ inch monel wire mesh. From the screen structure the water is conducted into the plant through ducts, pumped through the condensers and is returned to the river through concrete tunnels.

(1) Calhoun, 1952
(2) Fisheries No. 56

Temperature range of the river water at the intake varies from 45° F to 74° F, and under full-load operation of the five-unit plant the temperature of the water is raised a weighted mean of 16.2° F in its passage through the condensers. Condensers for Units 1, 2, and 3 are the single-pass type and condensers for Units 4 and 5 are the double-pass type. Two pumps supply water to each condenser, and it is the operating practice, regardless of load conditions, to operate both pumps.

Water velocities through the cooling water system average below 7 ft./sec. Calculated screen approach velocities are about 1.5 ft./sec., with velocities through the wire of approximately 2.6 ft./sec.

Passage time for fish from the traveling screens through the plant to the discharge structure is estimated at less than 4 minutes.

Provisions Made for Saving Fishlife

To stop eggs, larvae and small yearlings from passing through the plant, screens of extremely fine mesh would be necessary. Paradoxically, the hazard to delicate eggs, larvae and small yearlings was believed to be less in passing through the plant at the temperature rise anticipated than by being impinged on fine mesh screens. It was finally decided that ⅜ inch mesh screens would be satisfactory.

With the decision on mesh size, velocities were next considered. Screen approach velocities of 1.5 ft./sec. and water velocities through the wire of 2.7 ft./sec. seemed to present no undue hazard to fishlife and were accepted.

A device called a hydraulic fish lift was designed and built to collect and safely return to the river those fish too large to pass through the traveling screens and yet too small to swim back to the river through the inlet tubes.

Essentially, it consisted of two 8-inch diameter collector pipes installed one on each side of the approach channel to the screens. A number of oblong slots were cut along the length of each collector pipe, facing the screens and about 3 feet from them. The collector pipes were connected to a common manifold which, in turn, discharged to the river through a trough. It was thought that high velocity flow through the oblong slots and the collector pipes would forcibly and safely depopulate the area of fish. The high velocity flow was accomplished using the hydraulic eductor principle. Surplus water from the screen wash pumps was introduced into the collector system at a venturi section in the line.

It was recongized that his device would need field adjustment and experimentation to perfect its performance, and therefore only one device was made at the beginning.

The Start-Up of the Three-Unit Plant

The hydraulic fish lift proved inadequate in removing the great numbers of fish in the screen structure and the mortality rate of the fish recovered by the collector was high.

Concentration of live fish started building up ahead of the traveling screens and because of overpopulation and impingement on the screens the death rate began to rise.

State Department of Fish and Game biologists recovered numbers of dead bass by netting operations in the cooling water discharge. They attributed

the loss to the 12° F temperature rise of the cooling water and also warned that yearling salmon probably would not have the temperature tolerance of bass. Precedent and knowledge for a solution were lacking and it became evident a long-range research program was needed.

A Long-Range Research Program

Fishlife presents an ever-changing picture. Eggs and larvae of one day are small fish two or three days later and are yearlings 2 or 3 inches long within several months. The life cycle of one specie is not necessarily coincidental with the life cycle of another, which adds to the complexity of the problem. Studies for a one-year cycle are needed to get answers to the questions involved.

Knowledge and data are required on fish habits and behavior generally and answers to specific questions are needed. What effect on fish have currents of various velocities in screen channels? At what velocities are fish safe from impingement on traveling screens? Can fish stand impingement for any length of time? What size screen mesh should be used to best preserve fishlife? Can a fish stand a sudden temperature rise of the water, and if so, what temperature rise will prove lethal? What is the maximum temperature tolerance of a fish? Is there a greater concentration of fish near the surface, or are fish equally dispersed throughout the river water strata? These questions and many others must be answered before an economical and intelligent solution can be found to the fish preservation problem.

The answers to these questions became the basic objectives of the research program but time and space for this paper permit only a brief outline.

Fundamentally, the problem is twofold: the practical and safe return of trapped fish in the screen structure to the river and the safe passage through the plant of fish too small to be safely screened from the water used.

Fish Habits and Behavior Studies

Careful observation of fish habits and behavior characteristics under varying conditions was continuously carried on during the entire program. Since our problem deals with living animals, the more we know of these characteristics and habits the better able we are to understand their reactions. It is felt that this phase of the problem has been too often overlooked. Emphasis was placed on cause and effect in fish behavior.

It was observed that fish invariably swim headed into the current and this characteristic becomes more evident as the speed of the current increases. In quiet water fish were observed moving in all directions but with the first current movement they began to align themselves with their heads into the current and as the velocity increased this characteristic became more definite, with little tendency to deviate from it. It is believed that they do this to facilitate breathing and to feed more easily on passing food. Flume test experiments have confirmed this observation in velocities from zero to several feet per second.

Fish have rarely been observed swimming normal to or headed with the current except when they are frightened or exhausted and are desperately looking for a refuge.

Not all species respond identically, but as a general rule, the above seems

to be true. In the case of striped bass and king salmon little doubt exists in these characteristics.

It was observed that fish avoid areas of high turbulence and localities of wide differentials in velocity. They instinctively avoid areas of abrupt changes in stream flow. This bit of information is of great value in understanding their movements and in the control of fish.

Fish sense screened obstructions in a channel and will swim away from them if they are strong enough. If their swimming ability is equal to the current, they move laterally in front of the channel obstruction seeking a refuge or lower velocity area that they can negotiate. Only when a fish becomes exhausted or the current is beyond his ability, does it become impinged upon a screen obstruction. Again it should be noted that this characteristic varies with the specie of fish, its physical condition and its fighting spirit.

Velocity Studies

During the course of the research program much time was spent investigating and studying the effect of water velocity upon fish, both in the screen structure and experimentally in test flumes.

Seven test flume velocity experiments were conducted between February and October, 1952. Five were on striped bass and two on king salmon.

From these experiments the following conclusions were reached:

a) The swimming ability of yearling and juvenile striped bass and king salmon appear to be more a function of age than of size. Little difference was observed in the swimming ability of comparable salmon and bass and varied from 1 ft/sec. for the very small fish to over 2.75 ft./sec. for larger fish.

b) Many variables are involved in evaluating the endurance factor and again the endurance of yearling striped bass and king salmon appears to be a function of age rather than size. Barring physical injury, the hardiness of larval striped bass and small yearling salmon is amazing. The endurance factor for sizes and velocities noted above is 90 per cent or better.

c) Velocity as a function of fish mortality seems to be a logical way to determine the optimum velocity and this then raises the question of screen mesh size. This will be dealt with later.

d) The impingement of eggs, larvae and very small yearling bass appears to be fatal. Impingement is certain for they have little or no swimming ability. Salmon appear to withstand impingement for ten minutes without serious injury in the sizes we have to contend with at Contra Costa.

e) A maximum average approach velocity of 1.5 ft./sec. seems reasonable when all factors are considered. Striped bass and king salmon that can be safely screened from the water at any lower velocity can negotiate a current of 1.5 ft./sec. and this is especially true if nearby areas of escape are provided.

Screen Mesh Size Studies

Three separate experiments were conducted on yearling bass and king salmon in April, May and August of 1952 to determine the optimum size of

screen necessary for stopping fish of various sizes and age groups.

A test flume was equipped with interchangeable screens. Fish taken from the rescue operations were used. Mesh sizes were as follows:

a) 5-mesh screen with clear opening of 0.159 inches;
b) 4-mesh screen with clear opening of 0.196 inches;
c) 3-mesh screen with clear opening of 0.253 inches;
d) 2-mesh screen with clear opening of 0.375 inches.

Test fish were placed in the screened flume and held in a water velocity of 2 ft./sec. until they became impinged on the screen or had passed through it.

A summary of the results of two experiments with king salmon are as follows:

a) 5-mesh screen stops salmon 33 mm in length;
b) 4-mesh screen stops salmon 39 mm in length;
c) 3-mesh screen stops salmon 43 mm in length;
d) 2-mesh screen stops salmon 55 mm in length.

An experiment held on striped bass duplicating the test made on salmon produced the following results:

a) 5-mesh screen stops striped bass 27 mm in length;
b) 4-mesh screen stops striped bass 27 mm in length;
c) 3-mesh screen stops striped bass 30 mm in length;
d) 2-mesh screen stops striped bass 50 mm in length.

In analyzing these experiments the question resolves into size of fish to be stopped, bearing in mind the high mortality rate of small fish from impingement.

Any size fish can be stopped by screens of fine enough mesh, but if they are killed by impingement nothing has been accomplished in the solution of our preservation problem.

The swimming ability of small fish at a given velocity and its chances of survival from impingement appear to be the deciding factors in the choice of mesh size. Extremely small fishlife with little or no ability of self-propulsion will be impinged and killed at extremely low velocities, but they are more likely to survive if they are allowed to pass through the screen.

Taking into account the velocity experiments conducted, a screen of $\frac{3}{4}$ inch mesh clear opening seems to be the optimum size to be used with an approach velocity of 1.5 ft./sec.

Temperature Studies

Since the water taken from the river at the Contra Costa steam plant is used and not consumed, the question of safety in allowing small fish to pass through the plant was raised.

The principal hazard to fishlife in the trip through the plant is the temperature rise of the cooling water and experiments were conducted on striped bass and king salmon between February and October, 1952, having the following objectives:

a) The maximum temperature rise that juvenile bass and salmon could withstand;

b) Their maximum temperature tolerance;
c) The optimum temperature rise and maximum tolerance for design criteria in allowing small juveniles to pass through the cooling water system.

Both test flume and condenser experiments were conducted on bass taken from our rescue operation and hatchery and wild and rescued salmon were used.

The conclusion reached for yearling striped bass and king salmon of the sizes able to pass a-$\frac{3}{8}$ inch mesh screen was that passage through the plant constituted no great hazard and that the mortality rate was extremely low. Experiments showed yearling salmon can withstand a temperature rise of 25° F and have a maximum tolerance of about 80° F with no mortality. Yearling bass can withstand a temperature rise of approximately 16° F and have a maximum tolerance of about 83° F with 10 per cent mortality.

Development of Fish Collector

The development of the present so-called fish collector was the evolution of many devices tried for rescuing fish from the screen structure.

From the very beginning of the fish problem at Contra Costa it was realized that some safe method must be developed for collecting fish and returning them to the river alive.

It was hoped the vertical hydraulic fish lift would solve the problem. It was discarded, however, due to its high mortality rate and the fact that it did not depopulate the screen structure of fish. As an outgrowth of this device, a horizontal hydraulic fish lift was built and while it did little better than the vertical-type predecessor, it was another step forward.

Both of these devices were predicated on the belief that high suction was needed to literally suck the fish from the screen areas.

A device to be successful must remove fish safely and in large numbers. Several devices tried removed fish safely but they were cumbersome to operate and did not remove fish in sufficient quantities to meet the requirements.

A collector to operate satisfactorily must be located either where fish naturally congregate or where it will draw fish to it in large numbers. Drawing fish to the collector by employing high suctions was tried without success.

To solve this phase of the problem, a careful investigation of the screen structure was made looking for natural areas of high fish concentration.

From our experimental work on the characteristics and behavior of fish we had learned:

a) That fish have an acute sense of an approaching screened obstruction and if given an opportunity will swim away from the hazard;
b) That fish invariably swim headed into the current flow;
c) That fish will hunt out areas of low turbulence and velocities.

An area of about 15 sq. ft. was found directly in front of each screen bounded by the screen and by a submerged hanging curtain wall and appeared to be a natural concentration area for fish.

Into this area a large pan 8 inches deep was hung from the under side of the curtain wall, projecting into the area of refuge with the lip 5 inches away from the screens. The upper part of the pan and lip were open for their entire length and for a width of 13 inches back of the lip. The back end of the

pan was covered and gradually converged to an 8-inch diameter pipe which became the suction pipe of a pump located at the floor elevation of the screen structure.

Two different types of centrifugal pumps were tried. One was a 5-inch bladeless impeller horizontal pump similar to those used in sewage disposal plants. The second one was an 8-inch open impeller vertical pump of the trash disposal type. The pumps were of low capacity and therefore the velocities through the suction pipes were low. Likewise, the velocity at the entrance of the collector was less than 0.2 ft./sec.

Confirming the facts learned from previous studies on fish characteristics and behavior, fish were found to be quite content to enter the collector openings. Once committed to the collector with its gradually accelerating velocities and with no avenue of escape, the fish were pumped out of the screen structure and back into the river alive.

The collectors are capable of pumping hundreds of fish, from the smallest size up to approximately 12 inches in length with a mortality rate of 5 per cent or less. The collector appears to be the solution to the problem, after months of operation, not only for striped bass and king salmon but for all species of fish encountered at the plant.

The ultimate plan for the Contra Costa plant with its five traveling screens is to connect two collectors in tandem to each 8-inch pump for one pair of screens. This will require two 8-inch pumps for the four screens, and the fifth screen will be fitted with a collector connected to a 5-inch pump. All pumps will discharge into a common header which will discharge into the river at a flared submerged outlet.

It may be of passing interest to note that the 8-inch type of pump is being used by the fish canning industry for transporting fish from fishing boats to the canneries and that they pump as much as 65 tons of fish per hour without damage. On one occasion during fish unloading a seagull became accidentally entrapped and was carried through the pump and system a distance of 700 ft. after which it flew away. Fish as large as 18 inches have come through the pumps without visible sign of injury.

The collectors were fabricated out of plate steel and care was exercised in streamlining and rounding corners to reduce turbulence and injury to the fish.

The following graphs show results of bass recovery and mortality during one phase of the research program and illustrate the effectiveness of the fish collectors.

It should be noted that four screens are in service but only two are equipped with fish collectors.

Figure I

Distribution of Bass from All Methods of Recovery

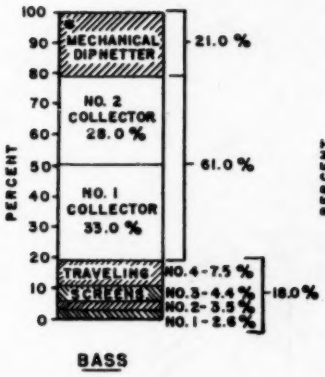


Figure II

Mortality from All Methods of Recovery

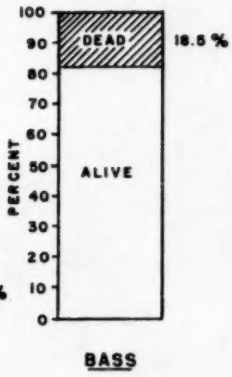
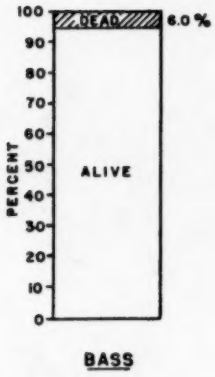


Figure III

Mortality from Fish Collectors



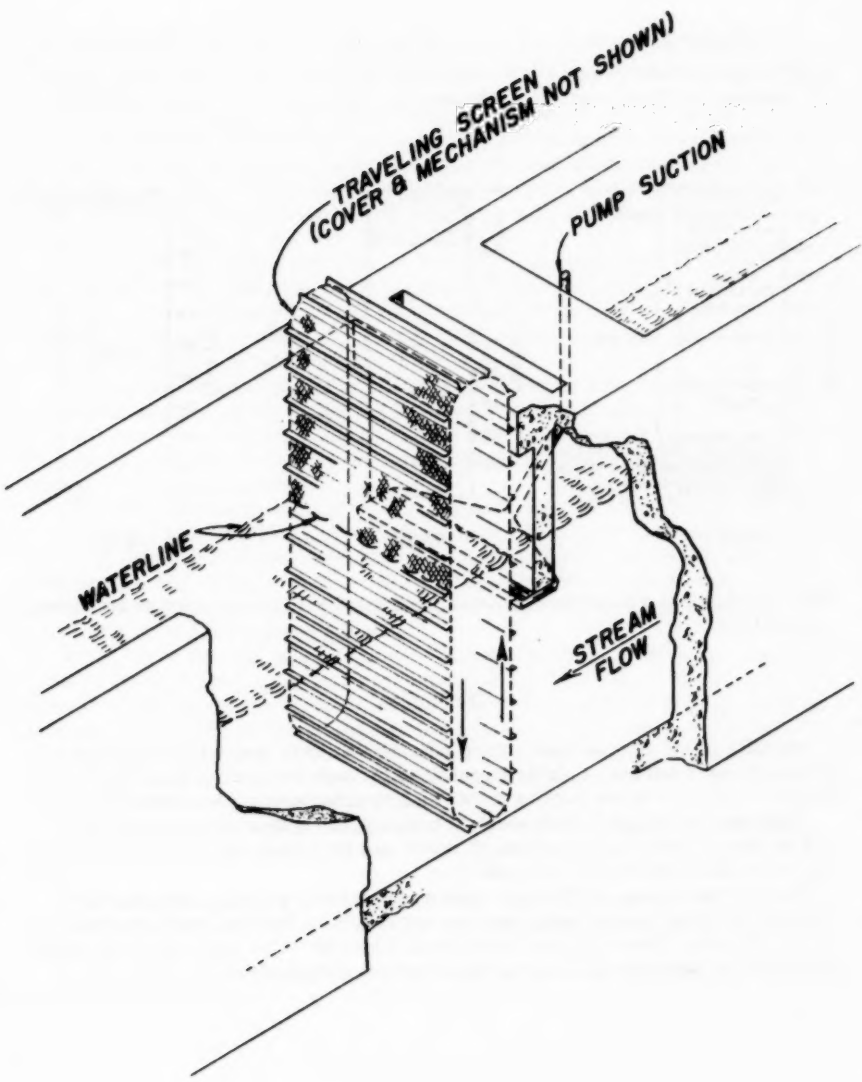
*The mechanical dip-netter was later abandoned with the addition of two more collectors.

Conclusion

Results of the research program indicate that bass and salmon passing a 3/8-inch mesh screen are able to continue through the plant with a 16° F temperature rise of the cooling water at a comparatively low mortality.

Fish barred by a 3/8-inch mesh screen and at an approach velocity of 1.5 ft./sec. or less in the screen channels can be safely recovered and returned to the river by the fish collector.

During the season of the year when small salmon and bass are passing through the plant, water temperatures are low, still further improving the mortality rate. Over-all fish mortality is expected to be less than 5 per cent in the use of water from the San Joaquin River in this plant.



ARTIST SKETCH OF FISH COLLECTOR